Sea to Summit to Sea Modeling
Total Water Budgeting and Decision Support

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The overarching goal of our research is a "Sea to Summit to Sea" integration of observations, numerical models and forecast systems to advance the science and obtain improved public safety and water management services. Advances in precipitation tracking and forecasting from the sea and across the landscape provide the foundation for improving land surface water budgeting and river flow forecasting. Given these "natural" flows it is further required that water management influences of reservoir storage and diversion be accounted to obtain accurate flow estimates throughout a watershed as the rivers track back towards the sea.

The Hydrometeorology Modeling and Applications (HMA) Team at NOAA ESRL Physical Sciences Division involves CIRA, NOAA and CIRES meteorologists, hydrologists, water resources and systems engineers working to develop and test an integrated system of observations, models and networks to demonstrate new environmental services that might be obtained for the National Weather Service (NWS) and other water management entities in the Russian River basin, CA. Partners involved include the California-Nevada River Forecast Center (CNRFC), the NWS Weather Forecast Office for San Francisco-Monterey (WFO-MTR), the Sonoma County Water Agency, the California Department of Water Resources (CA-DWR), the National Marine Fisheries Service (NMFS) and various other local water management agencies. These activities are an outgrowth of NOAA's 10-year Hydrometeorology Testbed (HMT) program.

Russian River, California

The Russian River watershed encompasses 1,485 square miles within Sonoma and Mendocino Counties, CA. It is one of the most flood-prone rivers in the State of California because of the watershed's unique geography and its exposure to atmospheric rivers (ARs) which produce heavy wintertime rainfall, frequent flooding and mudslides. In addition to the flood threat, ARs provide a main source of water volumes for water supplies for a burgeoning population of more than 600,000 in Sonoma County. There are tradeoffs between reservoir storage for water supply versus maintaining capture volumes for floods. And diversions for vineyard irrigation and frost protection continue to expand in response to high value wine industry demands. Further, endangered salmon fisheries require tributary and main stream flows during the late summer and early fall spawning season when precipitation is scarce and agriculture, recreation, and other water supply demands are high.
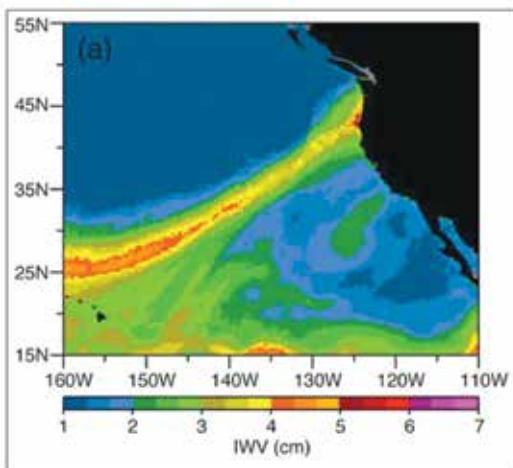

Russian River basin

Gridded Precipitation Information

Gridded precipitation information involves mapping of precipitation occurrence and forecasts as storms advance from the ocean over the land. An automated, objective tool for identifying and characterizing the integrated water vapor (IWV) signature of at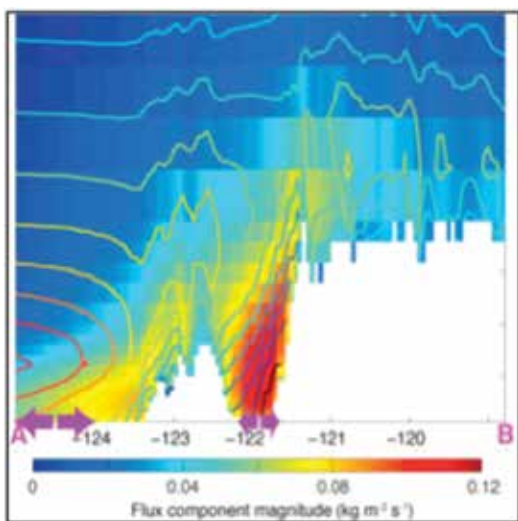mospheric rivers (ARs) based on satellite-observed or model derived IWV fields has been developed, demonstrated, and validated (Wick et al 2013). AR detection and tracking provides advanced lead time on incoming storms which can inform reservoir operations for floods and water supply. This tool is currently being tested in other parts of the U.S. to see if it has skill in identifying ARs and forecasting heavy rain events outside of the west coast region.

Atmospheric river as seen in water vapor analysis

Numerical weather prediction models are also being applied to provide forecasts of heavy rainfall events for the region. High resolution versions of the Weather Research Forecast (WRF) system are being applied that attempt to better represent orographic influences on wind patterns (i.e., barrier jet) and precipitation gradients in this mountainous region (Hughes 2012). Other forecast models being applied include the Global Forecast System (GFS) and High Resolution Rapid Refresh (HRRR) models.

Within the basin a primary research focus is to advance the capabilities of the Multi-Radar/Multi-Sensor System (MRMS). MRMS is a system with automated algorithms that quickly and intelligently integrate data streams from multiple radars, surface and upper air observations, satellite data and forecast models. HMA Team research has involved assessment of accuracy of alternate configurations of rain gage and radars for improved multi-sensor quantitative precipitation estimation (QPE), and refinement of radar Z-R relationships to west coast storms (Cifelli et al. 2013). Gap-filling radars provide a means to detect and track low-level precipitation fields as they progress inland. CIRA's Dr. V. Chandrasekar leads a team which develops and deploys these X-band radars in the mountainous terrain of coastal California (Lim et al 2013).

Orographic impact on Californian wind patterns in WRF

Gridded Hydrological Model

Coupling quantitative precipitation information (QPI) fields to a gridded hydrologic model (GHM) provides unregulated flow estimates at any grid location in the watershed. The Research Distributed Hydrologic Model (RDHM) developed by National Weather Service (NWS) is the GHM deployed for modeling surface runoff and soil moisture processes at the 4-km HRAP and 6-hr time step resolution; a 1-km, 1-hr version of the RDHM has also been developed (Hsu et al 2012; Johnson et al 2014). The GHM is based on data sets for terrain, grid connectivity, soils and vegetation. Various GPI fields noted above have been coupled to the GHM to provide a means for assessing model performance and forecast accuracy. Model ensembles will be developed soon for probabilistic forecasts and uncertainty estimates. GHM calibrations have focused on flood peaks, low flows and the total water budget for the simulation periods.

The coupled QPI/GHM system is being prototyped for real-time operations to determine its accuracy and help examine how it might be used to support NWS flash flood services. For this we have used the CHPS-FEWS system with RDHM developed by the NWS-OHD, which provides network ingest of real-time precipitation feeds (HRRR, CNRFC, MRMS). Remote logins allow researchers to access the GHM to perform retrospective model studies of various kinds as well as tracking flood events as they happen (e.g. December 2014). The FEWS workflows automatically trigger updating of the input data and forecast execution based on latest-available observed and forecast precipitation data.

Web-oriented displays of GHM output have been developed to provide animations of precipitation, flood runoff and soil moisture. These products can be accessed by any interested users and provide a means for extending the GHM assessment to the wider emergency and water resources management community in the basin.

Water Management Modeling

The remaining need is to apply water management models (WMM) to represent the influence that reservoirs and diversions have on the water balance on specific stream reaches. A key component for water management is Lake Mendocino located on the East Fork Russian River in the upper portion of the basin. This multipurpose reservoir is operated for flood control during the winter-spring seasons through maintenance of vacant space to capture flood flows. It is also operated for water supply and low flow augmentation for downstream fisheries and recreation purposes. Reservoir storage and release decisions are based on fixed "rule curves" which dictate release of flood waters to reduce storage levels regardless of whether there is another storm coming or not. There is interest in implementing more adaptive operation schemes that account for forecasts; so-called forecast-based operations (FBO).
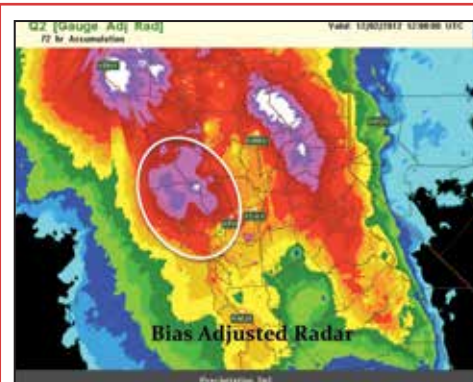
Adjusted rainfall estimates from QPI/GHM system
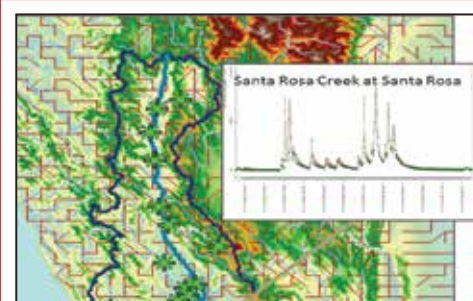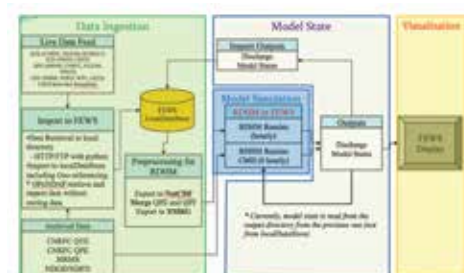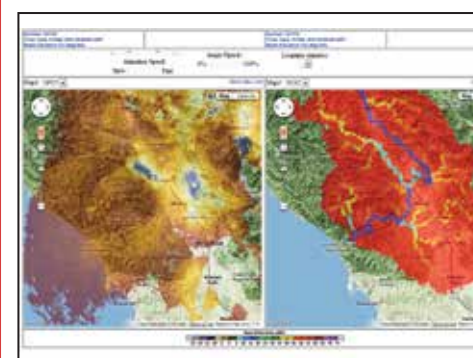

Potential use of QPI/GHM system

Diagram of QPI/GHM/FEWS system

Web deployment of GHM surface flows

A deterministic simulation model, called "FLDOPS", has been developed to examine how much additional water might be captured taking account of forecasts while maintaining flood mitigation levels (Johnson 2015). Preliminary analysis indicates that average water supply storage levels can be increased on the order of 10% (10,000 acre-ft) if account is taken of forecasts of no rain. If a large storm is forecast then a "pre-release" strategy can be used to evacuate storage space to maximize capture of flood waters. Further work is required to refine characterization of flood risks with the FBO strategy.

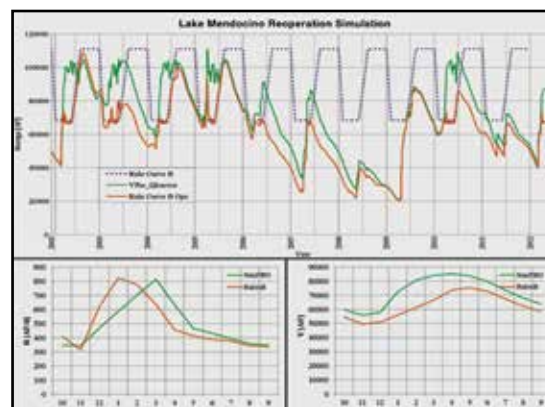Simulation of storage at Lake Mendocino using model

Uncertainty of forecasts must be translated into the risks that reservoir operations incur, especially for floods. Ensemble precipitation forecasts are routed through a hydrologic model to obtain ensemble streamflow predictions (ESPs) which can be routed through the reservoir using alternate operations policies. Reforecasts (Hamill 2006) provide ensembles of precipitation forecasts which can then be input to the Hydrologic Ensemble Forecast System (HEFS; Demargne et al 2014), which then generates the ESPs. The focus here is on applying intelligent agent-based modeling tools (Rieker and Labadie 2012) for learning optimal rules for reservoir forecast-based operations (FBO) that involve accounting for weather forecast-based anticipated runoff for reducing flow variability while increasing freshet runoff capture for balancing aquatic ecosystem preservation and flood control. We are investigating the most appropriate approaches for effective FBO under weather forecast uncertainty.

High resolution modeling of water demands for agriculture and environmental flows is being addressed using the GeoMODSIM software. Activities for the GeoMODSIM are described in the companion insert.
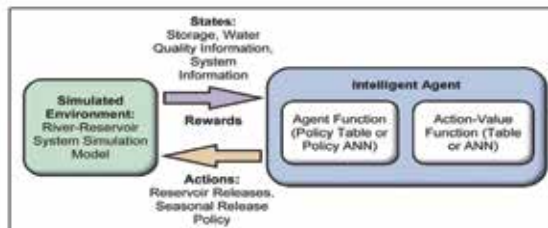

Diagram of intelligent agent interacting with simulated river-reservoir system.

Next Steps

Assembly of the collection of observations, models and systems integration tools provides a foundation for progressing on refinement of the tools and deployment to support real world applications for forecasting floods and environmental flows. Anticipated specific activities include:

- Generation of ensemble forecasts as input to stochastic optimization procedures directed to identifying optimal forecast-based reservoir operations policies.

- Seeking to advance the accuracy of current and forecast precipitation amounts through higher resolution monitoring (e.g. gap-filling radars) and advanced numerical weather and hydrological prediction modeling.

- Conducting assessments of the GHM to determine requirements for NWS flash flood operations, and concept of operations.

- Advance the coupling of precipitation forecasts with the GHM and WMM modules to obtain real-time guidance for water system operations that incorporates forecast uncertainty.

- Develop WMM tools to support collaborative examination of alternate water system operations by stakeholders in the basin.